POLICY RESEARCH WORKING PAPER 1788

An Economic Analysis of Woodfuel Management in the Sahel

The Case of Chad

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Charles Griffiths

An economic framework and computational method for assessing policy impacts on the cost of woodfuel supplies, and the spatial distribution of biomass, in a Sahelian woodland setting.

The World Bank
Policy Research Department
Environment, Infrastructure, and Agriculture Division
June 1997

Summary findings

The woodlands in some parts of the Sahel are effectively an open-access resource. Under open access, fuelwood cutters have no incentive to allow for benefits that might accrue if the wooded area were managed rather than mined. Those benefits include sustainable streams of fuelwood, fruits and other tree products, browse for cattle, and ecological services such as nitrogen fixation and erosion prevention. To remedy this problem, some Sahelian areas have moved to give communities effective control of local woodland resources.

To make it easier to analyze the economic cost of such supply-side interventions, Chomitz and Griffiths present an economic framework and computational method for assessing policy impacts on the cost of woodfuel supplies, and the spatial distribution of biomass, in a particular Sahelian woodland setting. They use spatial data on standing stock and on the costs of transport to market to model a supply curve of fuel to a fuel-consuming location. Given an exogenously specified demand, the model simulates, period by period, the extraction, regeneration, and transport of wood fuels. It also permits easy calculation of the dynamic cost of woodfuel depletion.

They apply the model to evaluate the benefits and ecological impacts of various scenarios for woodland management around the city of N'Djamena in Chad.

This paper — a product of the Environment, Infrastructure, and Agriculture Division, Policy Research Department — is part of a larger effort in the department to understand the causes and consequences of land use change. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Anna Marie Maranon, room N10-037, telephone 202-473-9074, fax 202-522-3230, Internet address prdei@worldbank.org. June 1997. (26 pages)

AN ECONOMIC ANALYSIS OF WOODFUEL MANAGEMENT IN THE SAHEL: THE CASE OF CHAD

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AN ECONOMIC ANALYSIS OF WOODFUEL MANAGEMENT IN THE SAHEL: THE CASE OF CHAD[1]

BACKGROUND AND OVERVIEW

The issue

In some parts of the Sahel, woodlands are effectively an open-access resource. Under open access, fuelwood cutters have no incentive to allow for the potential future stream of benefits that a wooded area might yield if it managed rather than 'mined'. These benefits include sustainable streams of:

- fuelwood, both for sale and for autoconsumption
- fruits and other tree products for direct human use
- browse for cattle, which translates into both meat and nutrient-rich dung
- other spillovers to agriculture such as nitrogen fixation and erosion prevention
- ecological services (including the intrinsic 'existence' value of the woodland ecosystem) which may be important although difficult to monetize

Undervaluation leads to overexploitation. The result is that the supply price of fuelwood rises faster than would be efficient if property rights could be costlessly enforced. At the same time, the flow of other woodland services is reduced. Furthermore, open access results in appropriation of fuelwood proceeds by a relatively small number of urban transporters rather than by the rural inhabitants of the woodlands.

Two sets of remedies have been proposed for this problem, and implemented in the Niger Household Energy Project (Foley et al. 1995):

Supply side: Villages can be granted the exclusive right to manage and harvest woodlands in their vicinity. With secure tenure rights, it is hoped that the villagers will be able to increase yields above the regeneration rates of degraded areas. Over the long run, it is hoped that

[1] We are very grateful to Neil Quarmby of I.S. Ltd for providing the GIS data used in this report, to Robert van der Plas and Luis Gutierrez for a variety of demand projections and supply parameters, to Djime Adoum for agricultural data, and to Emmanuel Akpa, Elias Ayuk, Amadou Cisse, Peter Dewees, Willem Floor, Axel Martin Jensen, Andrew Millington, Azedine Ouerghi, Mead Over, Alasanne Sow, Boris Utria, Max Wilton, and Roberto Zagha for help, useful discussions, and input. However the interpretations and conclusions of this report are not to be attributed to these people or to the World Bank, and the errors are ours alone.

increased supply from these close-in villages reduces the social costs associated with transporting 'mined' wood from increasingly distant supply sources.

Demand side: Demand-side interventions seek to introduce higher-efficiency stoves for charcoal, fuelwood, kerosene and LPG. An underlying assumption is that while these stoves are economically attractive to householders, market failures prevent their initial development and diffusion. For instance, they may not be effectively patentable; and skeptical consumers may be unwilling to purchase them until their performance has been credibly established. Once these hurdles are overcome, society benefits in lower effective energy costs and in lower exploitation of assumedly underpriced woodland resources.

Goals of this paper

The proposed remedies are quite plausible on *theoretical* grounds. Whether they make economic sense depends on a number of poorly-understood *empirical* magnitudes. For instance, if the productivity gains to woodland management are low relative to the costs of establishing tenure rights, then it may be economically more attractive simply to mine the resource -- however deplorable this would be from the standpoint of sustainability.

This paper examines the most important of the empirical and methodological issues involved in the economic analysis of the supply-side interventions.

1. How should the benefits of managed woodlands be assessed? We propose a simple framework for assessing project benefits which takes account of externalities, but does not require the explicit calculation of the shadow price of fuelwood.

2. What is the role and appropriate level of a wood tax? Taxes or 'user fees' have been proposed for a variety of reasons: as a mechanism for financing woodland management, as a device for discouraging production from unmanaged areas, and as a a Pigouvian tax on externalities. We discuss these rationales and propose a methodology for calculating the Pigouvian tax.

3. What is the impact of management on fuel supply costs? The key issue is what happens to the spatial distribution of resources over time, because that is the chief determinant of the transport cost and therefore the supply cost of fuelwood and charcoal. Here, we combine a simple but powerful methodology with extraordinarily detailed information about the spatial distribution of biomass in order to simulate the evolution of supply costs under different assumptions. The methodology permits us to address a broader range of questions, including the effects of kerosene and gasoline taxes and subsidies on woodfuel production.

4. What is the impact of management on the level and spatial distribution of biomass? The methodology allows us to simulate policy impacts on the density and spatial distribution of woodlands. This information can in turn be used to assess the ecological and social impacts of woodland degradation.

As an example, we apply this methodology to evaluate scenarios for a system of managed woodlands in Chad[2].

ANALYTIC FRAMEWORK

The analysis considers a project to stabilize the supply of woodfuels (wood and charcoal) to the city of N'Djamena. The project would place 320,000 ha of woodland under village management over a seven year period. Villages would be provided with technical assistance to delineate their woodlands, to manage them sustainably, and to produce charcoal with greater efficiency. Village production would be sold at authorized village markets, and subject to a village tax. Woodfuel production from unmanaged areas would be permitted, but subject to a larger tax upon entry to N'Djamena.

Project impacts: changes in the level and distribution of net benefits

The project changes the level, timing and distribution of various benefit streams. The conceptually simplest and most flexible way to assess the project is therefore to model the flows of those benefits and of their costs, with and without the project. This paper does so by using a simulation model to predict, over space and time, the production volumes and transport costs of fuelwood and charcoal; and the density of standing stock. These predictions form the basis for assessing economic welfare streams and ecological conditions. A detailed accounting of these flow and stocks permits three useful analyses listed below. (This paper concentrates on the first two, but provides the basis to undertake the third.)

1) Benefit/cost analysis: For those benefits which are monetizable, the aggregate benefit cost ratio can be computed as:

(NPDV of flow of benefits with project - NPDV of flow of benefits without project)/ (NPDV of costs)

Ideally we would compute, for each year and each scenario, the consumer surplus associated with the enjoyment of wood-based energy and the producer surplus associated with its production. To this would be added the analogous welfare gains associated with fruit, forage, and woodland-enhanced agricultural output. The present discounted sum of these welfare flows are then compared with and without the project.

Here we focus on the wood-based energy component, since it is presumed to be the largest source of benefits. We further assume that charcoal and fuelwood demand are price-inelastic

[2] This analysis was motivated by the proposed Chad Household Energy Project. However, the assumptions and project structure used for the current paper may differ from those used for the project appraisal.

(up to a crossover point at which it is preferable to switch to kerosene). This simplifies the calculation of benefits. These reduce to difference between the present discounted cost of supplying N'Djamena with fuelwood and charcoal with and without the project. The project potentially reduces the transport costs which represent the bulk of fuel supply costs.

2) Distributional analysis: The project promises progressive income redistributional benefits in addition to efficiency gains. Taxes, for instance, will redistribute income from urban consumers to rural producers, and the establishment of property rights will transfer producers' surplus from transporters to villagers. An accounting of production, costs, and prices for managed vs. unmanaged areas allows us to examine these redistributions.

3) Ecological impacts: We may intrinsically value woodlands and the ecosystem they support. In principle, one could use contingent valuation survey techniques to assess the dollar value of these benefits to the Chadian population and to the world at large. In practice, such estimates would be difficult to produce. However, we may still be able to quantify (if not monetize) the services if we assume that they are related to the extent and condition of the standing stock.

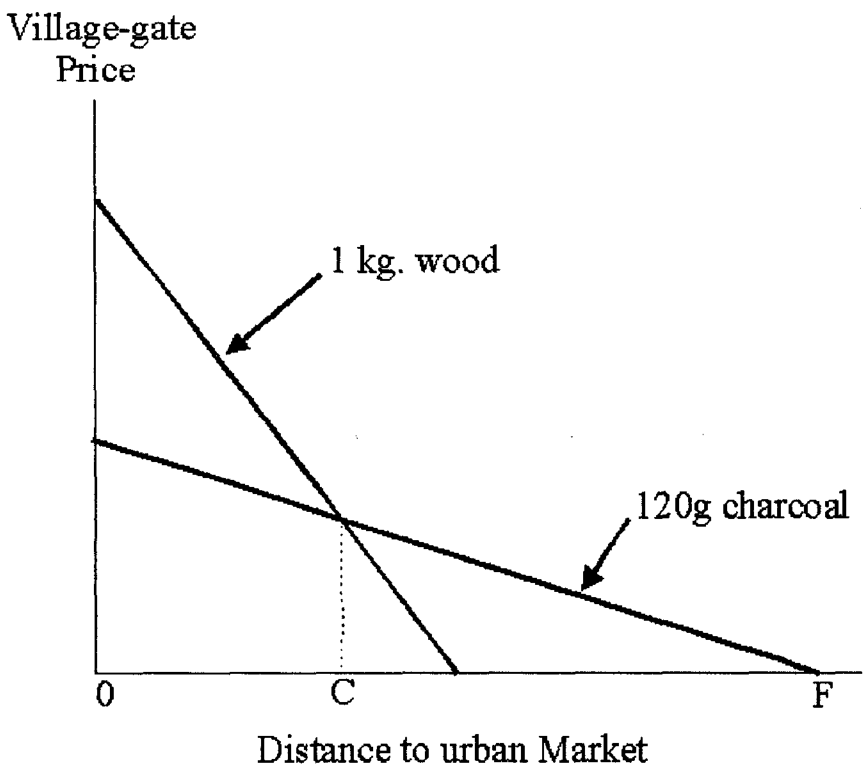
The fuelwood and charcoal market

The project will alter the entire market for wood-based fuels in the N'Djamena area. To assess the benefits of the intervention, and to understand the likely impacts of proposed taxes, it is necessary to briefly sketch a stylized version of the operation of the market.

All commercial woodfuel and charcoal demand is assumed to come from N'Djamena. This ignores the demand from small cities and towns. It assumes that rural dwellers satisfy their own energy demands from biomass sources which are largely (but perhaps not entirely) distinct from urban sources, such as crop residues.

<u>Supply side</u>
The wholesale prices of fuelwood and charcoal are determined in the N'Djamena market. Transport costs form a wedge between the urban wholesale price and the the 'village-gate' price of these commodities. Consequently the 'village-gate' prices declines with distance (or more precisely, transport cost) from N'Djamena. There is some evidence from Chad and elsewhere that this is the case.

Figure 1



These relations are shown in figure 1. The line marked 'wood' shows the price of 1 kg of wood as a function of distance from the urban market. The slope of the line reflects the transport cost per kg-km. The line marked 'charcoal' shows the price of the (approximately) 120 grams of charcoal which 1 kg of wood would yield. Note that, at the urban market, the price of the charcoal is less than that of the original wood. This reflects energy losses in the conversion process. However, the farmgate price of this quantity of charcoal falls off less rapidly than the bulkier wood from which it was derived. In other words, charcoal is a cheaper form in which to transport energy, because it contains three times as much energy per kg. The result is that between the urban market and crossover point C, woodcutters market their product in the form of wood; from point C to point F, wood is converted to charcoal; and beyond the frontier F it is not economically profitable to send wood to the urban market.

The supply curve for fuel is the mirror image of the declining village-gate price. Figure 2 is a stylized illustration of the close correspondence between the spatial distribution of biomass and the shape of the supply curve. The left panel shows a city surrounded by a ring of low-biomass savanna, scrub, or agricultural areas. The forest starts at radius r_0 from the city and extends indefinitely. Hence the lowest point P_0 on the initial supply curve S_0 of wood (as seen from the city) is the cost of transporting wood over the distance r_0. The supply curve rises gently, since the area of economic exploitation increases with the square of the radius. If, after a period of exploitation, the forest recedes to distance r_1, then the supply curve shifts upwards to S_1.

Figure 2

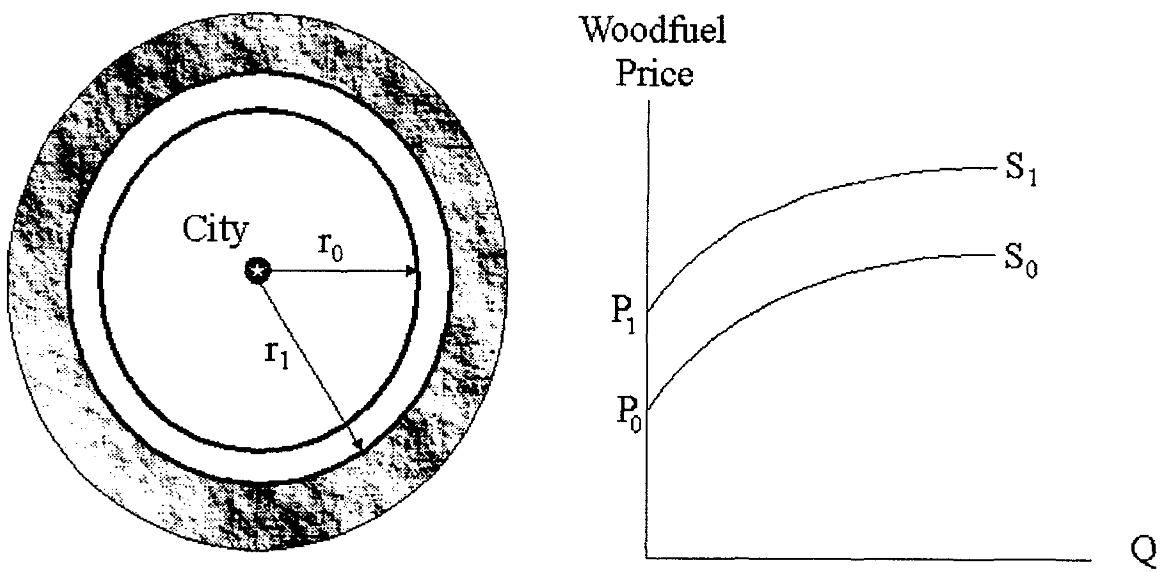
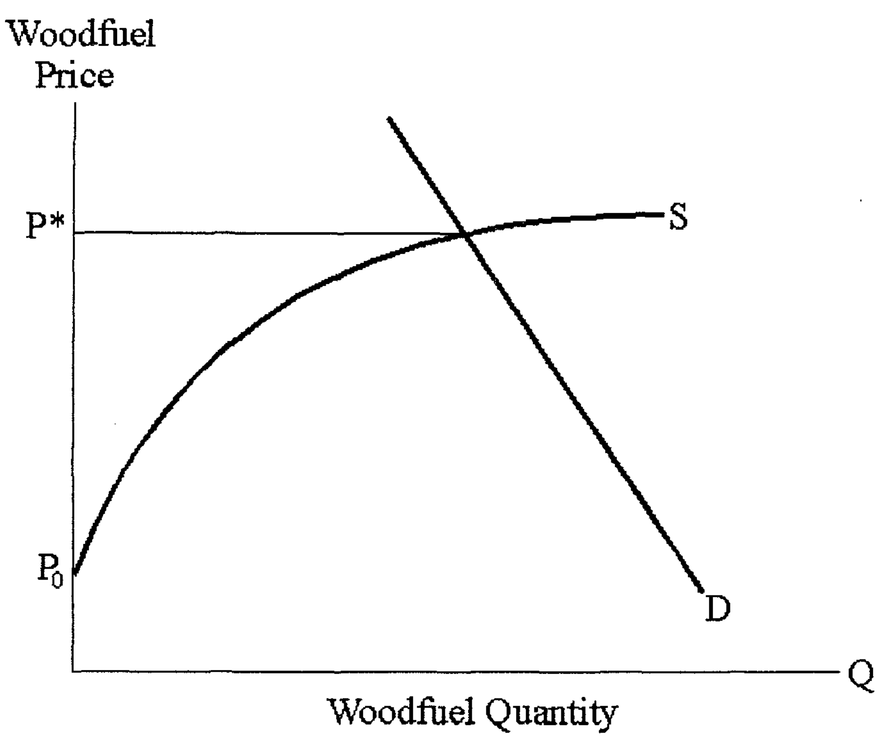


Figure 3



An immediate consequence of this simple model is that we would prefer to set up managed woodfuel markets as close to N'Djamena as possible. If villages close to the city are able to enforce their property rights, they will reap large locational rents because their production costs will be about the same as more distant villages, but they will receive a substantially higher price. For instance, figure 3 shows that a wood producer located in the closest woodland area would earn a rent equivalent to P^*-P_0, where P* is the market price and

P_0 the transport and production cost. The farthest supplying village would have production and transport costs of P* and would gain no rent. However, close-in villages may find it more attractive to convert to agriculture than to produce fuelwood, if agricultural commodity prices are even more distance-sensitive than fuelwood.

Demand side

For convenience, but following convention, we assume that the demand for fuelwood and charcoal is highly inelastic to changes in the wholesale prices of these commodities. The arguments are, first, that wholesale prices are a small portion of total price; and second (and more dubiously), that cooking habits are culturally fixed and insensitive to energy price. However, consumers are thought to be price-sensitive in their choice among fuels. Thus relative prices and energy contents determine switchover points between fuelwood, charcoal, and kerosene.

The justification and appropriate level of wood taxes

Two kinds of taxes have been proposed for this kind of project. Here we examine the rationale, feasibility, and appropriate levels of those taxes in light of the foregoing market sketch.

The rural market tax

One purpose of a village-level tax is to finance village-level woodland management activities and the administrative costs of operating the market. The appropriate level of this component of the tax is straightforward to compute. It has been suggested that additional taxes be levied in order to stimulate and finance community-level development activities. If we assume that demand is almost perfectly inelastic, then this tax constitutes an income transfer from urban consumers to the rural villagers, and could be set almost arbitrarily. This component of the tax is also supposed to induce village solidarity. That is, villagers will have an incentive to exert social pressure to prevent neighbors from selling wood outside the official channels, because of the loss of the village's share of the tax revenue. However, an individual making a rational calculation of his personal share of this foregone village revenue would probably not be induced to interfere with a neighbor's illicit activities. This incentive is probably symbolic at best. At worst, the tax may perversely encourage village woodcutters to bypass the village market.

The citygate tax

Following the example of Niger, a higher tax might be imposed on charcoal and fuelwood at the gates of N'Djamena. It would have two pragmatic purposes. First, it would ensure equity between managed and unmanaged producers. If only managed areas were taxed, they would be placed at a disadvantage, and some might be priced out of the market. Second, it could finance some of the project setup costs.

In addition, it could serve as a Pigouvian tax to counteract the external costs of open-access harvest. The main potential source of externality is the dynamic cost of utilization (Wiedenmann 1990): open-access exploitation shifts up the supply curve of fuelwood, increasing future costs above what they would be in a private-property regime. Additional externalities may also come into play. If one could compute the magnitude of the external costs and dynamic costs associated with fuelwood extraction, imposition of this tax would result in the socially optimal level of extraction, as purchasers are confronted with the full social cost of the resource. (In this paper we adopt the simplifying assumption that demand is perfectly inelastic. In this case the tax would not lead to a reduction in fuelwood consumption, but the tax proceeds could in principle be used to compensate society at large for the external costs.)

If Pigouvian taxes correct for the external costs of woodland depletion, why bother with setting up managed areas? Why not simply impose a tax? The answer is that the Pigouvian approach, by itself, will not lead to the introduction of improved management techniques which can potentially double yield rates per hectare. Those techniques will only be adopted if villagers feel confident in tenure rights -- which is a goal of the proposed interventions.

Note also that the tax should not be viewed as an enforcement mechanism for tenure rights, as is sometimes suggested. That rationale supposes that the high citygate tax will deter transporters from removing trees without villagers' permission. This however seems unlikely. If unmanaged areas dominate supply, or are the marginal suppliers of woodfuels, then a tax on unmanaged supply will shift the supply curve up. If demand is relatively inelastic, the both the price, and the rents accruing to untaxed managed areas, will shift up almost as much as the tax. Thus the incentive for outsiders to steal wood from managed areas is little diminished.

CALCULATING THE BENEFITS OF IMPROVED FUEL SUPPLY

Applying the framework

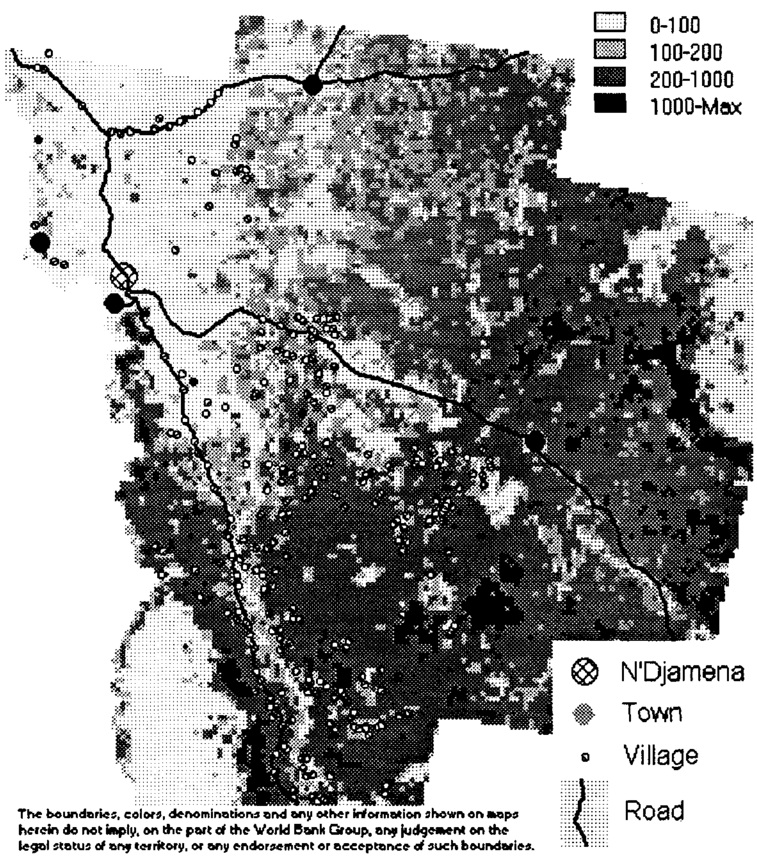
The most important component of hypothesized project benefits is the savings in fuel supply costs. Here we set aside (for later consideration and inclusion) the other benefits of woodlands and consider them simply as assets for producing fuel.

We have two options, corresponding to the with and without project scenarios. *Without the project,* woodland resources are 'mined' (cut down without regard to future regeneration), starting with the areas closest to the city. As mining proceeds, the supply frontier shifts further and further from town. Since the wholesale prices of wood and charcoal consist largely of transport costs, the result is a supply curve which shifts steadily upward, and with increasing total costs of supply over time (as in figure 2). The price may eventually stabilize at a high level corresponding to a backstop technology (kerosene) or supply source (a large but distant forest which can provide many years of supply). *With the project,* the supply curve also shifts up initially, because managed areas are placed out of bounds for 'mining'. In the medium run, this actually increases supply costs, because marginal supply must come from farther away. In the long run, however, the establishment of higher-yielding, sustainable supply sources stabilizes the supply curve below the long-run situation without the project. The net effect on supply costs is the difference between the net present costs of the with and without project scenario.

Does this formulation take account of the full social cost of wood extraction? Recall that there are two reasons why social costs exceed private costs. First, there are spillovers, external services to agriculture. These can be reckoned separately, simply accounting for the total value of such services with and without the project. (We do not calculate them here.) Second, there are the dynamic costs of wood supply, i.e. the impact of today's extraction on tomorrow's supply. To worry about this dynamic cost is precisely to worry that overexploitation causes the supply curve to shift upwards over time, and this effect is built into the model.

The simulation model

Map 1: Biomass 1995 (tons/km2)

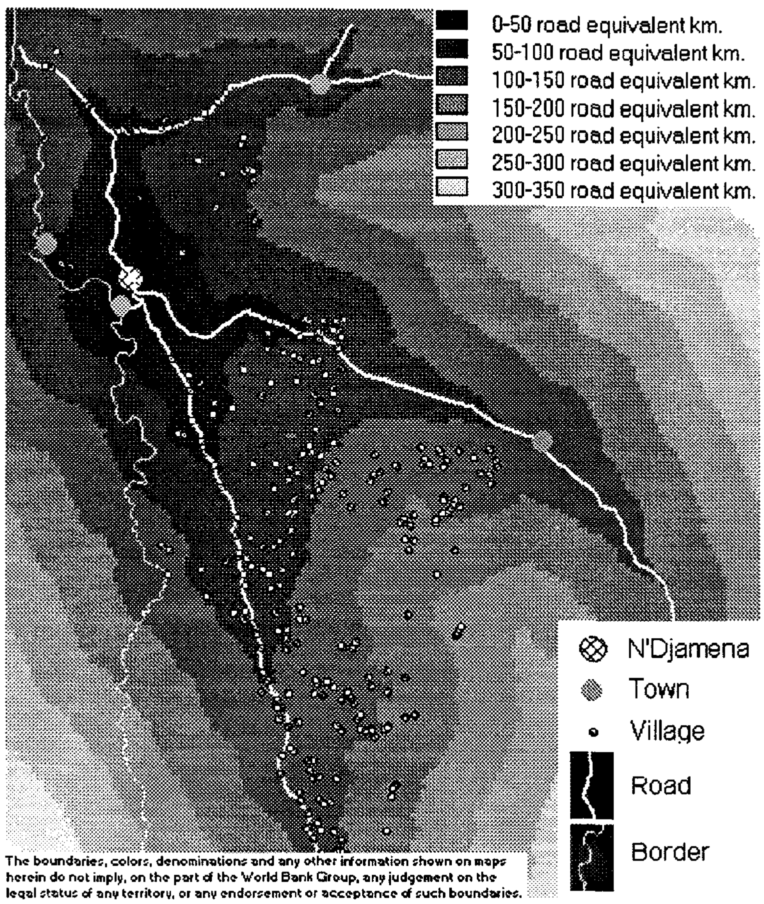


To compute the time-path of fuel supply costs, we construct a simple spatial simulation model of fuel supply for N'Djamena. The spatial model is apt for two reasons. First, as figure 2 illustrated, in order to draw the supply curve for fuel we need to understand the spatial distribution of resources, and how it evolves over time. Second, spatial models are the most appropriate way to represent the project's ecological impacts on the extent, location, and condition of habitat types.

We start with 20-meter resolution data on land cover for an area of approximately 20,000 square kilometers, encompassing N'Djamena's fuelwood supply zone (see Map 1). Applying biomass density factors, we aggregate this information into a 1 km grid of biomass density. For each grid cell, we estimate of the potential yield under sustainable vs. unsustainable exploitation, and the transport cost per ton to

N'Djamena (see Map 2).[3] Each year, the model satisfies exogenously-specified urban fuel demand at lowest transport cost. It starts at the closest (lowest transport cost) cell, 'mining' open access areas and harvesting from managed areas[4]. Tracing out the supply curve, the model exploits increasingly distant cells until total demand is satisfied.

Map 2: Transport Cost Zones (50 km intervals)



The model also allows for some land transformation. Since cultivated area in the prefecture has expanded rapidly over the past decade (see figure 4), the model converts an exogenously-specified area of some grassland, bushland and woodland to agriculture each year. It favors areas near N'Djamena and areas near existing agricultural lands. It also converts wooded grassland, bushland, and woodland to managed areas at an exogenously specified rate. Supply for the following year depends on the spatial pattern of stock depletion and regeneration this year; in effect, the supply curve is shifted every year. Presuming that extraction rates exceed regeneration rates, for instance, supply will come from progressively farther areas over time.

The model allows for two backstop technologies. When all woodlands in the vicinity of N'Djamena are depleted, it allows unlimited supplies of wood to be brought in from distant regions in the south and east of the country, at a high cost. (The total standing stock in Chad is estimated at 859 million tons, which if mined would serve N'Djamena for a millenium at current consumption levels). The model also allows a switchover from charcoal to kerosene when the

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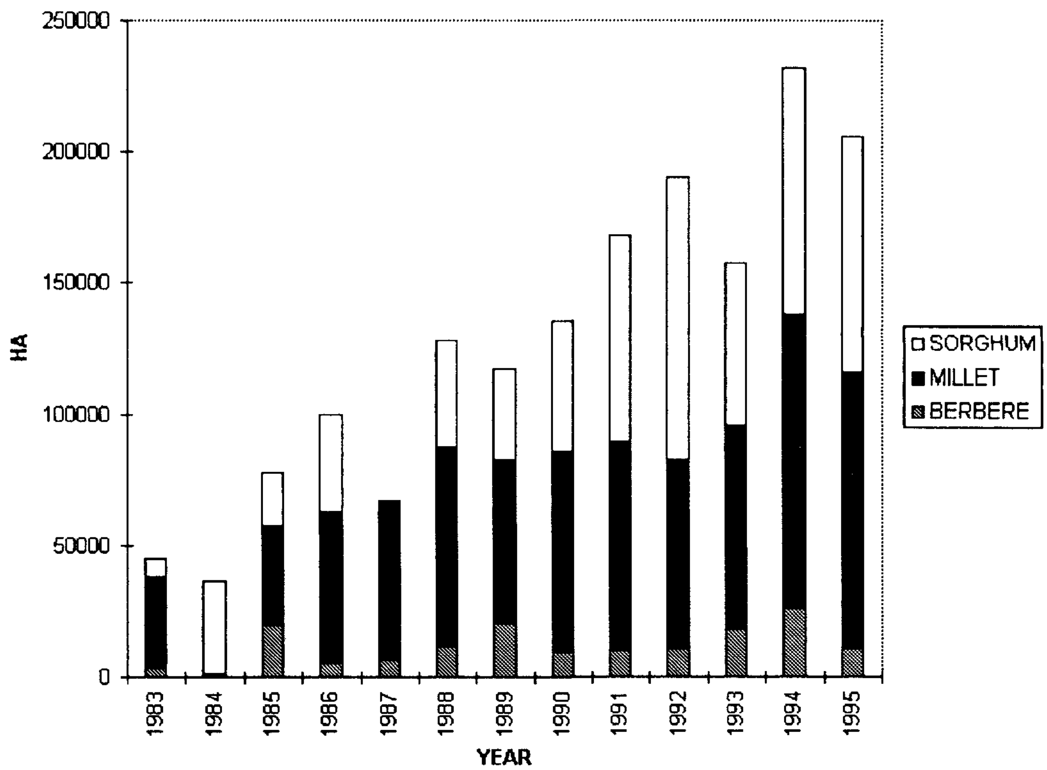
[3] On this map, N'Djamena is the cross-hatched white circle; main towns are black circles; villages are small black squares; the primary roads are shown in black, and the border with Cameroon in white.

[4] Areas in Cameroon are not considered as sources of potential supply. There are however high-density stands of Sudanian woodland in Cameroon relatively close to N'Djamena.

efficiency-corrected retail energy prices of the two fuels are equivalent.

Figure 4

CULTIVATED AREA, CHARI-BAGUIRMI



The present discounted social cost of meeting demand is tallied over the simulation period. This is the output of chief interest. Additional outputs include the spatial distributions of biomass over time, and the evolution of market price. It is also possible to calculate producers' surplus (locational rents) for producers in managed and unmanaged areas.

[See the Appendix for more information on the data, parameters, and assumptions underlying the model.]

RESULTS OF ANALYSIS

Initial conditions

How close in N'Djamena to sources of fuel supply? How close is the land available for conversion to managed woodlands? Table 1 shows the current distribution of land cover types according to travel distance from N'Djamena.[5] 'Other' includes scrubland, inundated grassland, and settlements. The striking message of these data is that there is relatively little suitable management area close to the city. The project proposes to put about 320,000 ha under management. But within 100 km of N'Djamena there are only about 46,000 ha of acacia bushland (mean biomass, 8.5 tons/ha) and about 10,000 ha of Sudanian woodland (mean biomass, 35 tons/ha). It is not clear whether it is worthwhile managing the the 41000 ha of semi-desert wooded grassland (mean biomass, 1.7 ton/ha), but even if this area is included, it would still be necessary to go past the 125 km mark in order to meet the 320,000 ha goal.

Table 1: Distribution of land cover (ha) by travel distance from N'Djamena (km)

Distance	grassland	bushland	woodland	agriculture	other	total
0-25	2243	1135	499	1430	34894	40200
26-50	8352	3113	1044	6445	96745	115700
51-75	13499	10900	3037	17959	149604	195000
76-100	17837	31309	5576	32584	140394	227700
101-125	18628	51080	8225	34833	136634	249400
126-150	60635	296884	62882	133021	594878	1148300

Simulation results, reference runs:
Assumptions for the with-project and without-project scenarios are shown in Tables 2a and 2b.

Table 2a: Basic parameters: managed vs. unmanaged areas

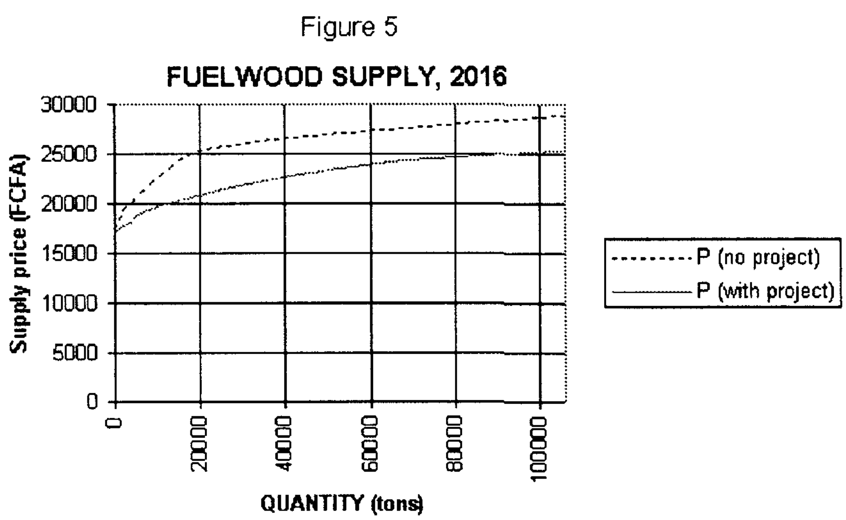
Parameter	Unmanaged areas	Managed areas
Regeneration rates (tons/ha/yr):		
Semi-desert wooded grassland	0.4	0.8
Acacia bushland	0.6	1.2
Dry Sudanian woodland	1.2	2.4
Charcoaling efficiency	0.13	0.20

[5] Travel distance is measured along the cheapest path, where secondary road travel is assumed to be twice as costly, and off-road travel four times as costly, as travel along the primary roads. The unit is the equivalent number of kilometers along a primary road.

Table 2b: other parameters

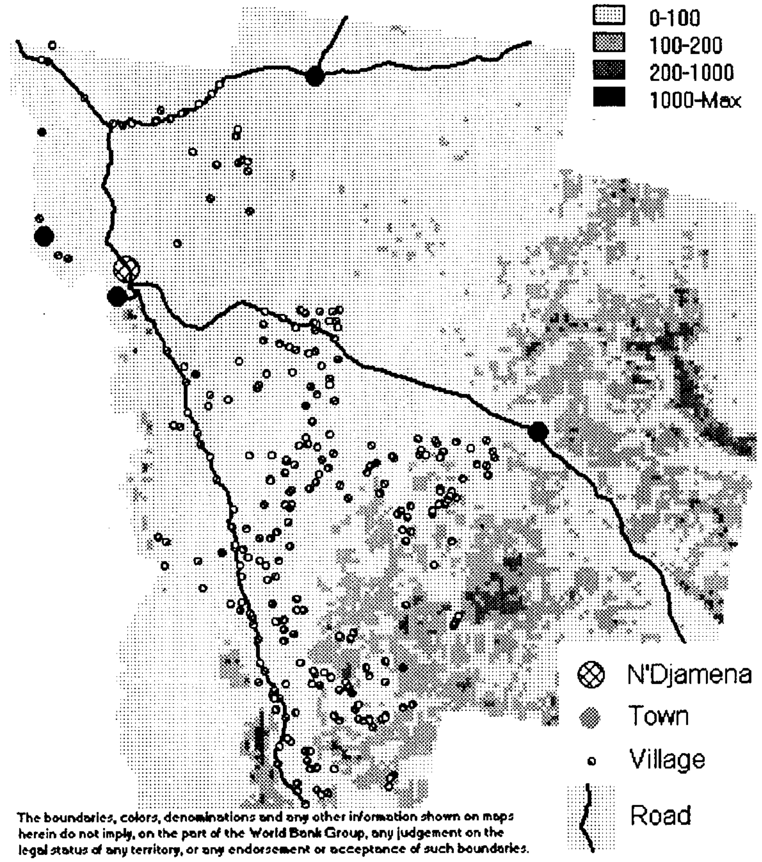
Discount rate	12%
Spontaneous agricultural expansion	10,000 ha/yr, first 10 years
Transport cost	86.4 FCFA/ton-km
Charcoal tax	FCFA 15/kg (with project scenario only)
Tax collection efficiency	rises from 0.10 to 0.77 over 11 years
Kerosene price	initially $0.43, declines to $0.38 after two years

Under our base assumptions, the deforestation frontier widens rapidly, both with and without the project. With the project, biomass is preserved within the managed areas, but is otherwise reduced to minimal levels within a more than 200 km radius of N'Djamena. A comparison of maps 3 and 4 shows the difference. Significant biomass persists in the without-project assumption only in areas which were formerly high-density Sudanian woodland -- and this because of a debatable assumption that only one-third of the standing stock is exploited by open-access cutters.



Figures 5 and 6 show the final-year supply curves for fuelwood and charcoal, both with and without the project. (These supply curves are net of tax.) The area between the curves represents the current savings in fuel supply costs due to the project. The simulation program implicitly calculates these supply curves for each year and sums the discounted value of the savings. The present discounted value (PDV) of fuel supply cost savings, with the project, is about $5.9 million over a 22 year period. For comparison, a rough estimate of the present discounted value of project costs is $3.9 million.

Map 3: Biomass 2016 (without project)



Map 4: Biomass 2016 (with project)

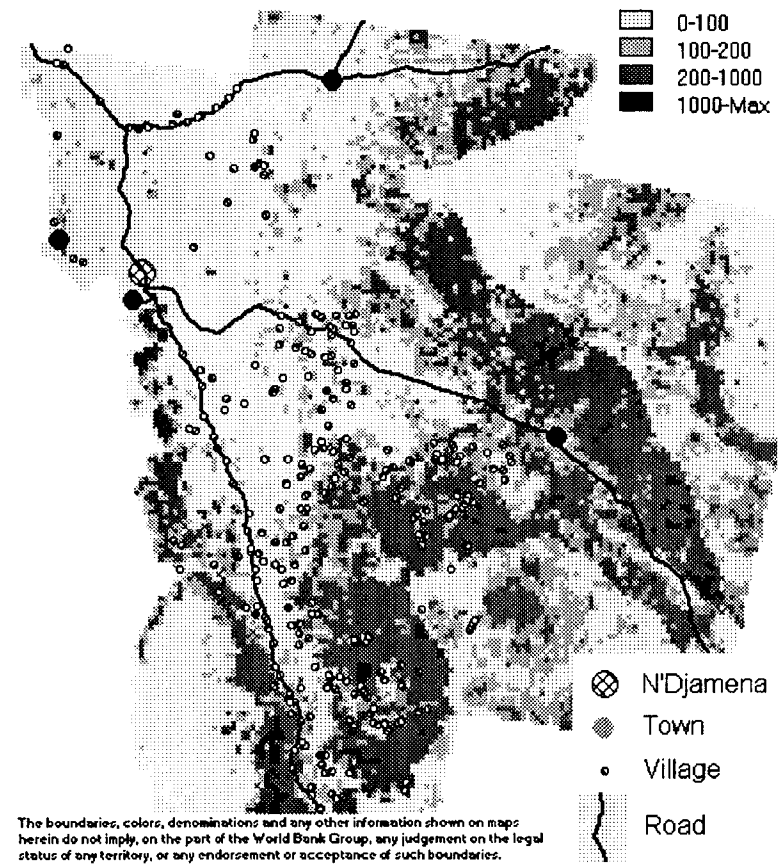
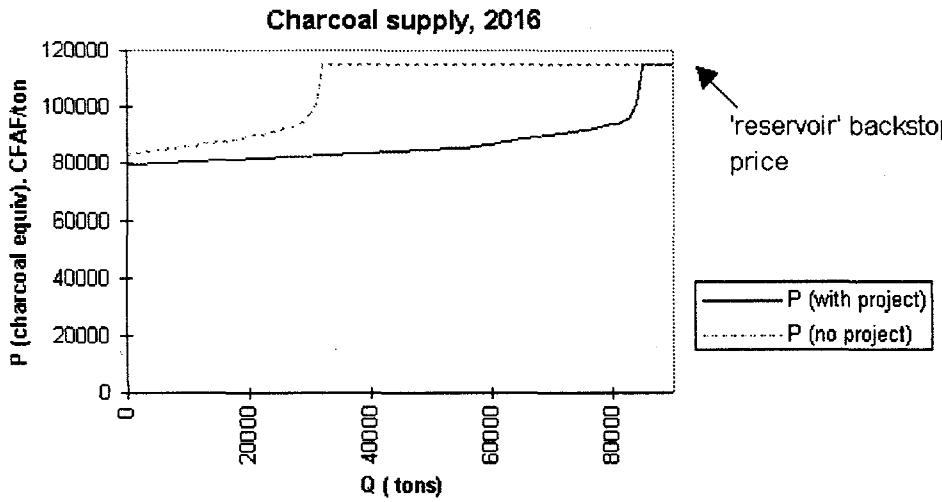


Figure 6



Sensitivity analyses

Since the benefits may be sensitive to assumptions about parameters whose true value is unknown, we undertook sensitivity tests (see table) as follows:

Charcoal Demand Elasticity	Backstop supply source, km	Yield increase under management	PDV Supply cost, w/o project, FCFA billion	PDV supply cost, with project, FCFA billion	PDV of supply cost savings with project, $ million
-.25	390	50%	57.9	56.6	$2.6
-.25	390	100%	57.9	55.3	$5.3
0	**390**	**100%**	**62.3**	**59.5**	**$5.9**
0	580	100%	63.5	59.7	$7.9

Demand elasticity. The benefits turn out not to be very sensitive to variations in the demand elasticity in charcoal, which we implemented crudely via reductions in charcoal demand as a function of estimated price rises[6].

Cost of backstop wood supply. Benefits are somewhat sensitive to assumptions about the cost of the 'backstop' wood supply. Chad has a great deal of wood -- what is at issue is its accessibility. We have good data on supply only up to a radius of about 250 km (primary-road-travel

[6] We do not allow for the small changes in consumer surplus which result when demand is not perfectly inelastic.

equivalent) from N'djamena, and partial coverage up to about 390 km. Hence the program will show an unrealistically steep climb in supply price after the 250 km mark, which will be cutoff at the backstop.(This is evident in figure 6). However, because these distant areas are reached only after a decade or more, the discounted savings are not terribly sensitive to the shape of the supply curve at this point. We experiment with two assumptions about backstops: a) an elastic supply of charcoal at an equivalent distance of 390 km (equivalent means that cost per ton-km is being held constant -- actual distance could be larger if more efficient long-haul transport is being used; b) an elastic supply at 580 km (this is equivalent to boat transport from the Sahr region, using our standard assumption about cost per ton km). We prefer the closer backstop assumption as it compensates for our underestimate of supply in the 250-390 km range.

Regeneration rates. Regeneration rates are poorly established. Our standard assumption is that managed regeneration gives twice the per-hectare yield as unmanaged areas of the same land cover class. Reducing the yield gain from 100% to 50% reduces the savings by about half, perhaps to less than the cost of implementing the project.

Unit costs of transport. For the scenarios presented here, project-related savings will be directly proportional (up to a point) to the assumed unit cost of transport. (Very high unit costs of transport might result in a switchover to kerosene rather than exploitation of the fuelwood 'reservoir'.) The project appraisal team used an estimate of 86.4 FCFA/ton-km, which is 20% lower than the mean of a small informal sample of transporters taken in February 1996. It is considerably lower than the costs used by a recent World Bank transport study, but the lower figures are reasonable in light of the size and age of the vehicles involved in charcoal transport. We have taken the 86.4 FCFA figure to represent transport costs along primary roads, and assume that costs are twice as high on secondary roads and average four times as high on tracks and off-road.

Growth of agriculture. The scenarios reported above assume an exogenous growth in agricultural land of 10,000 ha/year for ten years, roughly continuing past trends. We reran the base scenario with alternative assumptions of a) no agricultural expansion; and b) expansion of 20,000 ha/year for ten years. The results were surprisingly insensitive to these assumptions. With no agricultural expansion, the savings decreased very slightly, while with more rapid agricultural expansion, they slightly increased. This is because, with more rapid displacement of the fuelwood frontier, there are greater returns to establishing close-in sources of managed supply.

Efficient charcoal conversion

The analysis assumes that managed areas adopt higher efficiency charcoal to wood conversion techniques. Failure of this technology to diffuse would result in lower charcoal production in managed areas, and lower savings.

Dynamic costs of woodfuel extraction

One advantage of the methodology presented here is that it facilitates calculation of the dynamic costs of woodfuel depletion. This external cost is defined as:

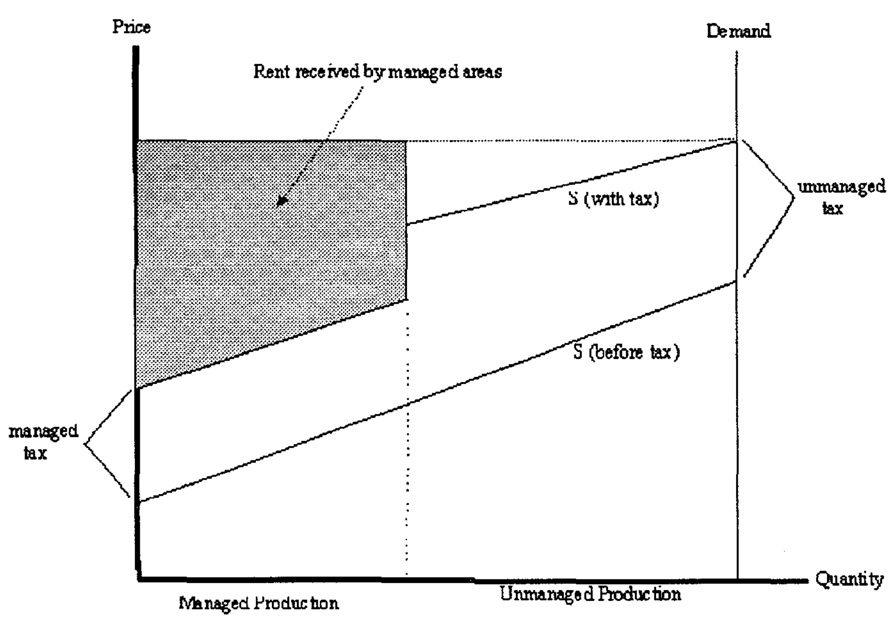
dynamic costs =
∂ (PDV of all future fuel supply costs)/∂ (quantity extracted) - current unit cost of supply

In other words, the current costs of supplying an extra ton of wood are less than the total cost of supply, because an extra unit of extraction today forces all future supply to travel a slightly greater distance.

We compute the marginal change in the total discounted value of fuel supply costs (over the next twenty years) of a marginal increase in production this year. Under our base assumptions, this dynamic cost exceeds the current costs by about 4600 FCFA/ton. It would therefore justify a Pigouvian tax of at least that level.

Distributional impacts
The project has potentially significant redistributive effects. These occur because managed woodlands close to town get large locational rents (ie. producers's surplus) which we assume was formerly appropriated by the transporters. In addition, since marginal supply always comes from nonmanaged areas, the tax differential on nonmanaged production boosts the price received by the managed areas, resulting in an additional rent transfer.

Figure 7



This is illustrated in Figure 7, which is schematic. The supply curve (without tax) is related to the distribution of supply sources by distance from N'Djamena. The further from the city is a plot of woodland, the higher is its delivered price of fuelwood or charcoal in the city; the supply curve consists mostly of transport costs. If we assume that managed areas occupy the region closest to town (which is the efficient strategy), then the left part of the supply curve describes managed areas, and the right side, unmanaged. The actual supply curve faced by consumers is derived by adding the tax. The higher tax in nonmanaged areas results in a supply curve with a step in it. The revenues received by the close-in managed areas are greater than their costs and tax liabilities. Their producers' surplus (or locational rent) is shown by the shaded area.

The calculated rent capture is quite large, with a PDV of nearly $10 million. This probably overstates the gain, since some villagers currently succeed in capturing some part of their locational rent.

CAVEAT: IS DEGRADATION REALLY PROCEEDING AS FAST AS PREDICTED?

Our projections rest on a large number of assumptions about basic parameters. Unfortunately it is difficult to verify the plausibility of our projections from historical data. The IS study tried to compare 1987 Landsat imagery with 1995 SPOT imagery to detect land cover change, but differences in sensors and in season of imagery acquisition make comparison difficult. The tentative results showed approximately 330,000 ha of woodland increase in the study area of approximately 1.5 million ha. Much of this increase represents a change from Landsat-classified scrub to SPOT-classified woodland, and may be spurious. An approximately equal area of woodland loss (348000 ha) was reported. Some of this loss, however, represents agricultural conversion east of N'djamena or between the Logone and Chari rivers. Some woodland loss does reflect fuelwood exploitation, but we are unable to hazard a guess at the net biomass change in the study area.

One might expect that if resource degradation is rapid, the combination of an upward-shifting supply curve and an outward shifting demand curve (from urban growth) should result in rising prices[7]. Again the evidence for this is contradictory. FAO (1995) reports volatile retail charcoal prices in N'djamena over the period 1983-1987, varying between 38.5 and 58.1 FCFA per kg; ESMAP (1993) reports prices for 1992 ranging between 40 and 50 FCFA. This suggests approximately stable real charcoal prices over the period 1982-1992. (Charcoal prices subsequently doubled following the devaluation of the franc, but this reflect the change in transport costs rather than resource degradation).

This ambiguity about the rate of degradation reflects a broader uncertainty about the scope of the 'fuelwood crisis'. A number of authors have questioned the conventional wisdom of receding woodland frontiers, rising fuel prices, and increased fuelwood gathering times (Leach and Mearns 1988, Benjaminsen 1993, Leach and Fairhead 1994, Dewees 1995, RPTES 1995, Foley *et al.* 1995 chapter 7). The crux of the problem is that there is relatively little reliable information on changes in woodlands, biomass, or fuel prices over time – and what little there is, is ambiguous. In Burkina Faso, over a ten-year period, forest cover decreased around Ouagadougou, but biomass actually increased due to the retention of trees on farms and to

[7] Dewees (1995) and Leach and Mearns (1988), caution that year-to-year variation in wages (due to competing harvest demands), temperature, and agricultural clearing of woodlands, results in woodfuel price volatility which could dwarf long-term trends.

increasing densities in remaining forests (RPTES 1995). In the neighborhood of Kano, Nigeria, biomass increased close to the city, but decreased at greater distances. (Nichol 1989) In Kissidougou, Guinea, an historical and ecological analysis found that villages created rather than consumed forest 'islands', leading to increased forest cover over 1952-1991 (Leach and Fairhead 1994).

If we are overpredicting the rate of fuelwood depletion, then either our demand estimates are too high, or we are grossly underestimating natural regeneration rates, or underestimating fuelwood supply from agricultural areas, or overestimating the unit cost of transport, or are mistaken in the assumption of open access. In any of these contingencies we would be overestimating the benefits of the project. It would therefore be desirable to benchmark the model against actual land cover change data, using comparable land cover interpretations over a multiyear period. This also underlines the need for better estimates of key parameters.

EXTENSIONS AND RESEARCH NEEDS

Extensions

The model presented here takes fuel demand to be completely price-inelastic. In future work we will incorporate a demand function which will allow for equilibrium determination of prices, quantities, and the spatial pattern of supply. This will be important if price elasticities are greater than we have assumed.

A topic of particular policy interest is the effect on fuelwood extraction of taxes and subsidies on petroleum products. Chad, like other countries, levies a tax on kerosene. Preliminary investigation suggests that, as woodland depletion elevates the price of charcoal, removal of the kerosene tax would result in a switchover from charcoal to kerosene at the margin. This would arrest the advance of the deforestation frontier and result in net social savings in fuel supply costs -- assuming the price of kerosene does not rise, and that the government finds an alternate source of revenue. On the other hand, increases or decreases in the market price of gasoline will affect the economic radius of fuelwood and charcoal extraction. A deeper exploration of these countervailing effects will be useful in anticipating the environmental effects of fiscal policies.

Related research needs

The estimates presented here are heavily qualified because of lack of information on some basic physical and behavioral relationships. For a number of years, authors such as Dewees (1995) and Leach and Mearns (1988) have cautioned that the conventional view of a woodfuel 'crisis' in the Sahel was based on a large number of assumptions unsupported by careful empirical measurement. These include assumptions that fuelwood gathering (rather than agricultural clearing) is the major cause of Sahelian deforestation, and that urban woodfuel demand is relatively inelastic. These assumptions are testable. Yet despite their importance to our understanding of fuelwood issues, and despite two decades of projects and studies on fuelwood, these basic assumptions have been virtually untouched by empirical research.

Some priority areas for research include:

land cover change -- It would be useful to assemble remote sensing data for two points in time for Chad and other areas of the Sahel, and undertake an analysis of the extent, nature, and location of land cover change. To what extent are woodlands being degraded? To what extent are agricultural areas displacing woodlands?

regeneration and production rates -- There are ongoing studies of regeneration in a number of countries. These need to be collated, compared, and analyzed. Of particular importance is comparing unmanaged to managed regeneration rates, and measuring fuelwood supply as a byproduct of agricultural land uses.

fuel demand elasticities -- Survey data could take advantage of spatial or temporal variation in the price of fuels in order to estimate price elasticities.

fuelwood extraction and agricultural production-- Does open-access fuelwood extraction result in reduced productivity in crop production? The answer depends on the extent to which: a) fuelwood transporters remove trees from fields or fallow areas; b) the net benefits provided by trees to crops, such as erosion prevention and nitrogen fixation. Quantitative evidence on point a) is lacking; in many areas farmers effectively exercise tenure over trees in fields.

rural utilization of nontimber tree products - There is little information about rural peoples' use of trees for fruits, forage, and nonmarketed fuel. Information on both the levels, and the spatial range of extraction of these benefits is necessary for accurate assessment of the economic and social benefits of woodlands, and hence of the external costs of woodland depletion.

This is especially true for forage. Fodder from trees is important for cattle, especially in the dry season (Bonfiglioli 1993). It seems plausible that the higher local run-down of biomass predicted in the without-project scenarios would harm village-based cattle-owners, and might displace nomadic cattle-owners, possibly resulting in territorial conflict.

implementation of the Niger Household Energy Project -- This project, which enjoys some fairly good built-in monitoring systems, is yielding ongoing information about the functioning of managed and unmanaged markets. It deserves greater attention and analysis.

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Appendix: Simulation model: data, assumptions, and parameters

Implementing the simulation model requires a host of simplifying assumptions. It also requires assumptions about parameters for which empirical measurement is lacking. Despite these uncertainties, the model puts a considerable amount of structure on the problem. It is grounded in fairly good measurements of the current distribution of biomass, and imposes logical consistency on the interrelation of extraction rates, regeneration rates, agricultural conversion rates, transport costs, market price and standing stock. Uncertain parameters may be easily varied to explore the sensitivity of results.

Below we briefly review some of the data, parameters, and behavioral assumptions of the model.

Land cover distribution and biomass
Land cover data were kindly provided by Neil Quarmby of IS, Ltd. and are described in the IS report: "Domestic Energy Project: Fuelwood Inventory in the region around N'Djamena", Jan 1996. They are based on SPOT satellite imagery for 1994/95 supplemented by IS groundtruthing and fieldwork in Nov. 1995. The IS interpretations distinguish the following classes: grassland, bushland, woodland, inundated grassland, agriculture, scrub, other. Biomass factors (dry wood equivalent density in tons/ha) were taken from the IS report (with aggegation in some cases). Zero biomasses were assigned to agriculture, scrub, and inundated grassland, though in fact there may be extractable biomass in these classes.

Transport costs
For each cell, relative transport cost to N'Djamena was calculated as follows. Cells on the primary roads were assigned impedances (relative cost of travelling through the cell) of unity. GIS data on secondary roads was not available; however, village location data were available, and the village locations trace out the secondary road network fairly well. Therefore cells within 2 km of villages not on primary roads were assigned an impedance of 2; this traces out a pattern of secondary roads with travel costs twice as high as on primary roads. Cells within 4 km of a major town were also assigned impedances of 2, reflecting the assumed presence of many secondary roads and tracks. All remaining cells were assigned an impedance of 4 (ie. travel costs on minor tracks are assumed four times as high as on primary roads). Standard GIS techniques were then used to compute the least-cost path from each cell to N'Djamena; the cost for each cell implicity incorporates both on and off road transport.

These relative costs must be scaled by a monetary cost per ton-km. A 1992 World Bank transport study which estimated ton-km costs of FCFA 121/ton-km; adjusting fuel costs for the recent devaluation, this becomes FCFA 142. We follow van der Plas and Gutierrez (1996) in using a conservative figure of FCFA 86.4.

Regeneration rates

The economic viability of the project depends on the relative regeneration (or production) rates of fuelwood in managed versus unmanaged areas. Unfortunately these are not known with precision. A variety of experiments have suggested that improved techniques for coppicing, combined with protection against agriculturalists' bush fires, can result in higher yields under management. Jensen's authoritative review (Jensen 1995) cites Catinot (1994) as the most reliable source, with an estimated yield under management of 1.0 to 1.5 m3 (0.8 to 1.2 tons) per ha per year in areas with annual rainfall of 400-800 mm. This increases to 2.0 to 3.0 m3/ha/yr for rainfall of 800-1200 mm. (N'Djamena's rainfall is on the order of 600 mm; rainfall increases to the south of the city). For comparison, forest reserves in Mali (which encompasses the same ecological zones as Chad) report yields ranging from 0.361 m3/ha in bush savanna to 0.869 m3/ha in tree savanna to 1.374 ha/yr in woodlands. In Niger, the 38 managed markets operating in 1994 sold 51730 steres of wood (Foley et al 1995); allowing 2000 ha/market, that translates to an annual productivity of just 0.2 tons/ha, but this low figure may reflect partial year reports and start-up problems.

The situation is less clear in areas which have been subject to open-access exploitation. A basic question is whether these areas become permanently degraded. Jensen (1995) attributes most degradation to bush fires rather than to excessive woodcutting; this begs the question of the prevalence of bush fires and the extent to which the project would discourage those fires. Jensen (1994) suggested that a reasonable estimate of regeneration in the exploited areas would be approximately 75% of Clement (1982), ie. 0.225 to 0.675 m3/ha/yr for rainfall of 400-800 mm and 0.675 to 1.5 m3 for rainfall of 800-1200 mm.

Jensen (1995) suggests that agricultural areas may be important sources of fuelwood or other fuels. A 1990 forest inventory of Burkina Faso found that cultivated and fallow areas had standing stocks of trees (>10 cm diameter) ranging from 3.0 m3/ha in the north to 5.4 in the south. This compares favorably with areas classed as wooded grassland in Chad. However, the simulation program assumes that there is no production of fuel in agricultural areas.

The program takes as parameters, annual regeneration rates in tons/ha for each class of woodland (wooded grassland, bushland, Sudanian woodland, managed woodlands). We have roughly mapped these woodland classes onto different rainfall categories in order to suggest regeneration rates. These class-specific rates are applied regardless of current standing stock, subject to standing stock being less than pre-specified maxima for each class.

Spontaneous agricultural conversion. According to official reports, agricultural area devoted to staple crops has been rapidly expanding in Chari-Baguirmi prefecture, which encompasses the fuelwood supply area. Area devoted to sorghum, millet and berbere increased from about 45,000 ha in 1983 to 205,000 in 1995 (see figure 4). Presumably this growth reflects in part the growth of the urban market.

As noted earlier, the IS study (Quarmby *et al. 1996)* appears to detect some conversion of woodlands to agricultural cultivation. If agriculture yields substantially higher returns than woodfuel production, such conversion is presumably efficient and should not be seen as posing a fuelwood 'problem' -- unless it is unsustainable and itself results in land degradation.

We thought, *a priori*, that it was important to take account of agricultural expansion, because conversion of woodlands to agriculture will potentially affect the time path of fuel supply in both the with-project and without-project scenarios. While we lack the data to predict expansion, the simulation program allows exogenous specification of the annual number of hectares to be converted. This demand is fulfilled starting near the city by assuming that the rate of conversion within a cell is proportional to the existing extent of agriculture within the cell. This simple heuristic captures the ideas that a) current agricultural locations are proxies for areas with suitable agroclimatic conditions; b) controlling for agricultural suitability, areas near town are the most attractive candidates for conversion. The model does not allow conversion of inundated grassland, scrub, or managed woodlands.

Designation of managed woodlands

The program takes as exogenous the annual number of hectares to be converted to management. It does not convert agricultural areas, or those covered in scrub. (These exclusions may be too conservative.) Each year, conversion demand is satisfied starting with the closest available bushland to N'Djamena. This maximizes both the efficiency gains and capture of locational rents associated with the institution of managed woodlands.

Discount rate

The current flow of project benefits may be negative in the short term; it is only in the medium to long term that positive benefits are felt. Hence the social discount rate will be an important determinant of project viability. We have applied a discount rate of 12%. This can be easily varied.

Demand for fuelwood and charcoal

An ideal model would include fully-specified demand function for fuelwood, charcoal, kerosene, and LPG, incorporating cross-price elasticities and stove choices. This is well beyond the scope of the current exercise. We take as exogenously specified for each year the demand for charcoal, fuelwood, kerosene, and LPG. These demands were taken from van der Plas and Gutierrez (1996). We assume completely price-inelastic demand within these categories -- except that we allow for a switchover from charcoal to kerosene if the efficiency-adjusted price of energy content is the same. (The price of kerosene over time is an input to the model.) Thus kerosene is a backstop technology, placing a ceiling on the price of charcoal and therefore on the extent of deforestation.

The model fulfills all fuelwood demand as close as N'Djamena as possible before starting to fufill charcoal demand. This reflects the well-known economic dominance of fuelwood at short distances.

The model allows differential efficiency in wood-to-charcoal conversion between managed and unmanaged areas. Since achievement of higher efficiency requires higher labor costs, the high efficiency techniques is used only where either the input price is high or where the available stock of wood is limited. Neither condition obtain in unmanaged lands; imposition of a charcoal tax will not affect the production incentives in these areas. Villages in managed areas would not be influenced by a wood tax (since they self produce), but might have an incentive to use higher efficiency techniques because of limitations on their annual wood production. This incentive will depend on whether the increase in yield, multiplied by the village-gate price, exceeds the extra production costs. Villages distant from N'Djamena might not have an incentive to adopt the more efficient techniques.

Backstop technologies
Two backstops limit the potential rise of fuel prices. The first, mentioned above, is kerosene. Since kerosene deliver twice the effective energy per kilogram, consumers become indifferent between kerosene and charcoal when the per-kg price of the latter rises above half the price of kerosene. (This abstracts from the costs of stove acquisition, which would delay switchover. Consumer preferences for the convenience of kerosene vs. the alleged better taste of charcoal cooking will also affect the switchover point). The second backstop is the availability of woodfuels from distant but very large 'reservoirs'.

Open access
Finally, the model presumes that all areas not deliberately and painstakingly placed under village management are open access. In fact, a variety of tree tenure institutions are found throughout the Sahel, so it would be worth verifying the true extent to which urban woodcutters have unimpeded access to trees and woodlands.

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